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ABSTRACT

A study of earth-covered schools in Oklahoma was conducted for the Federal Emergency Management Agency (FEMA) to assess the viability of these structures as learning and teaching environments, as cost beneficial investments, and as potential shelters from natural and man-made disasters. The study was aimed at identifying what information is currently available to define broad trade-offs between earth-covered and traditional schools, applying this information to provide an initial quantitative assessment of costs and benefits, and defining what additional studies and measurements might be desirable. Major areas considered were sociological, physiological, and psychological functional adequacy of earth-covered schools; economic differences, their costs and benefits; and practical aspects of disaster protection. A summary of the benefits of earth-covered schools reached at a workshop in Oklahoma is included. From the study it is concluded that an excellent opportunity exists for FEMA to develop sufficient hard data on benefits of earth-covered schools that will generally influence decisions in favor of more such structures. (Author/MLF)

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AN EMPIRICAL STUDY OF EARTH COVERED SCHOOLS IN OKLAHOMA

prepared for

Federal Emergency Management Agency
Washington, D.C.

Contract No. DCPA01-78-C-0265
Work Unit 1151 E

by

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Study of fifteen schools concerning social attitudes toward earth covered structures; comparative construction, design, and real estate costs; energy; disaster protection factors including radiation and blast protection upgrading.

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INTRODUCTION

In any major catastrophe, or disaster situation, the first objective becomes survival. The first step towards survival under most disaster conditions is to find sanctuary. An important element in an effective preparedness program, then, is to establish a safe area for victims where they may regroup to face the problem.

The list of potential catastrophies, or disasters, is a long one. It encompasses earthquake, cyclone, tornado, hurricane, flood, volcanic eruption, tsunami, fire, chemical spill, reactor failure, plague, riot, insurrection, invasion, war, etc. Preparedness for a full range of disasters is beyond the physical and economic capability of any society, though a basic, systematic approach may provide protection against a broad range of them*. For this reason, success in the endeavor will depend on how readily and unobtrusively preparations can be integrated into day-to-day affairs.

For many years, thoughtful civil-preparedness planners have recognized the fact that schools are strategically located in communities insofar as serving the public is concerned. Hence, schools constitute one of the most promising opportunities to develop an infrastructure of local sanctuaries to provide the first level of response to emergencies in times of disaster.

Nowhere has a recurring disaster provided greater motivation for initiating the kind of development envisioned than in the State of Oklahoma. Historical observation and hard data on the frequency of tornadoes and the resultant damage has stimulated the development of an increasing number of earth covered schools to provide safety to children during school hours, and to serve as community sanctuaries in time of need. Investigation of this evolving, local disaster-preparedness phenomenon can provide further insights

* Contemplating and preparing for disaster has never been popular with the masses, however.

useful to the Federal Emergency Management Agency (FEMA). To help with this task, Scientific Service, Inc. (SSI) has assembled preliminary information on earth covered schools in Oklahoma to enable FEMA to evaluate the potential of these structures as a means to enhance preparedness, on a national scale to survive natural and man-made disasters. It also appears possible that The Department of Energy could become an important ally in this task because energy conservation has become a strong alternative driving force (to storm protection) in the move to earth covered schools.

OBJECTIVE

The present program was aimed at identifying what information is currently available to define broad trade-offs between earth covered and traditional schools, applying this information to provide an initial quantitative assessment of costs and benefits, and defining what additional studies and measurements might be desirable. Major areas to consider were:

1) Sociological, physiological, and psychological functional adequacy of earth covered schools,
2) Economic differences, their costs and benefits,
3) Practical aspects of disaster protection.

The first task was to ensure earth covered structures were acceptable as a teaching and learning environment. The second task was to identify additional incentives (besides tornadoes) for building schools underground. The third task was to evaluate structural performance of Oklahoma's earth covered schools under realistic disaster loading conditions, as built, and to assess the degree to which this performance might be upgraded simply, to improve it. Two levels of upgrading were to be considered, options that could be implemented in a matter of hours on existing structures, and inexpensive options that could be introduced at the time of design to be incorporated during construction.

As each of the above factors regarding earth covered schools proved favorable, increasing rationale has been provided for a practical program

that could be developed to encourage an increase in construction of such schools to provide a network of sanctuaries strategically located to the public. Quite simply, if alternative incentives (e.g., energy conservation) were to be actively documented they could become the motivating force to promote earth covered construction of public schools. Then a program to promote construction of more earth covered schools could be developed using a strategy that would enable the disaster protection aspect to be included unobtrusively. It may be presumed this approach would greatly simplify FEMA's management task of getting public disaster protection into place but, of course, it will be necessary for these school structures to be suitable for, or readily convertible to, sanctuaries. Thus, this aspect will have to be included as an integral part of any continuing program.

PROGRAM APPROACH

The program was initiated by the Defense Civil Preparedness Agency (now FEMA) with the State of Oklahoma Civil Defense Agency. The latter subcontracted the study in three parts. The portion dealing with societal, physiological, and psychological aspects was conducted by Moreland Associates. The portion dealing with comparative economic costs and benefits of earth covered versus traditional schools was conducted by the Oklahoma State Department of Education. The portion dealing with structural performance was conducted by Scientific Service, Inc. In addition, SSI was requested to summarize the findings of all these studies in this single report.

METHODS

By definition, the societal and psychological factors are a consensus of opinions, rather than facts. Coservation suggests that whatever other benefits might accrue to an earth covered school, it would still be unacceptable if it did not provide an adequate learning and teaching environment. Consequently, the most critical factor to acceptability is how the teachers, students, parents, school superintendents, etc. react to, and feel about earth covered schools after some years of involvement. Surveys and interviews conducted individually and collectively by Moreland Associates

provided input in this area. The Moreland Associates report is enclosed as Appendix A, and the findings are discussed in the next section.

To make an economic comparison of costs and benefits of earth covered versus traditional schools, data on design and construction costs, operation and maintenance costs, and related items were required from Department of Education archives. Not all of the desired data were explicit and some assumptions had to be made in the interpretation. The general findings of this portion of the study are discussed in the next section. A more detailed summary report (Ref. 1) has been prepared by the Oklahoma State Department of Education and published by the State of Oklahoma.

Assessment of the structural performance of earth covered schools, both as they currently exist and with inexpensive modification, required an analysis of the design and specifications for each. Because the structural performance of interest was that under emergency conditions (rather than day-to-day demands) a structural engineer with a background in wind, earthquake, and nuclear phenomena was assigned this task. Concepts applied have been detailed in a general report on methods for upgrading structures to provide enhanced disaster protection in emergency (Ref. 2). Basically, the ability of a structure to resist unusual mechanical, thermal, and radiation loads provides the most comprehensive measure of disaster protection. These three pertinent indices of disaster protection were evaluated for the twelve earth covered schools studied under this contract. (The data were summarized in Ref. 1.)

DISCUSSION OF WORK COMPLETED

Sociological and Psychological Aspects

Through interviews and via discussion groups, it became apparent that the underlying reason for building earth covered schools in Oklahoma was to provide protection from tornadoes. However, since inception, most Oklahoma communities with earth covered schools have begun to appreciate other benefits. Prominent among these are preservation of open space, and conservation of energy. Neither of these benefits, nor storm protection, would suffice to effect acceptance of earth covered schools if the learning and teaching environment were not acceptable. To evaluate this question careful studies of student achievement, student and teacher anxieties, and

parent opinions were carried ou with respect to the first completely underground school in the world (built in 1962) according to Ref. 3. The findings with regard to these indices were positive in favor of the earth covered school environment, i.e., there were no distinguishable differences from such indices measured in traditional schools.

The present study, by Moreland Associates, has augmented the data in support of the acceptability of earth covered schools by seeking to draw upon the communities themselves to elaborate on other benefits or on any perceived shortcomings that might require attention. The value of this kind of assessment does not lie in further corroboration of the obvious: i.e., that earth covered schools are acceptable, or that storm protection against tornadoes is no longer a necessary driving force in the decision process (though this may be true more often than not in Oklahoma). The very fact that more earth covered schools are being built, and in states within the United States where tornadoes are rarely, if ever, seen, are prima facie evidence that these assessments are correct. Rather, the real need for this kind of effort is to characterize the nature and sequence of thoughts and opinions that lead to a decision to build underground, so these may be reinforced through development of hard data necessary for solving inhibiting problems, and for decision making. Development of pertinent hard data requires some idea of just what constitutes a relevant decision factor to those charged with making decisions.

Virtually any factor that generates concern or excites interest is a decision factor. The relative rankings of these factors provide insight and a guide to receptivity depending, of course, on the responsibility and authority of the respondents. The survey data was aimed at those responsible for Oklahoma school system decisions. Decision factors so identified are included in the outline that follows. General factors are given as the major headings with more specific factors listed below them.

<u>Sociological, Physiological, and Psychological Factors</u>

Environmental

Land Use

Esthetics

- Psychological
  - Learning and Teaching
    - Achievement
    - Ease
  - Attitudes
    - Community Security
    - Innovative Appeal
    - Invisibility
- Physiological
  - Comfort (allergies)
  - Accessibility (handicapped)

Economic Factors

- Initial costs
  - Real Estate
  - Design & Construction
- Operation and Maintenance
  - Utilities
  - Cleaning
  - Painting
  - Repair
  - Alterations
  - Replacement
  - Insurance

Security Factors

- Disaster Protection
  - Tornado
  - Fire
  - Vandalism

There are complex interrelationships between, and among, many of these. Nevertheless, once subjective factors are identified it becomes possible to consider ways to measure and assess them in a more quantitative manner.

It is human nature to resist change and to be concerned about any changes that are made. When such concerns fall into sociological and psychological categories it is necessary to find a way to measure possible changes. (Measuring physiological changes is much more straightforward.) In the case of earth covered schools, measurements were made of student achievement, student and teacher attendance records, etc. The net result has been to provide evidence that favors the earth covered school both in regard to learning and teaching environment. Thus, attitudes regarding Oklahoma's earth covered schools now seem to be at the stage of evolution, where opinion preferences, i.e., likes and dislikes, are the prevailing concern here* and the principal deciding factors fall to economic and security aspects.

Economic Aspects

Economic analysis is straightforward provided the records have been kept and the data are explicit. The Oklahoma Department of Education provided data from their archives to compare design and construction costs, obtained estimates of current land values to examine real estate costs, and obtained data on annual energy consumption from fuel and electric bills. (Unfortunately, most of the earth covered schools are not metered independently, but as part of a complex that includes traditional structures. The reason is that there is a monthly charge for each meter and one such charge seems enough.) Consequently, the energy metered was simply allocated according to the relative areas (earth covered versus total).

It would seem that the design and construction cost data assembled were adequate, but the change in construction costs from 1961 through 1978 make it impossible to draw direct comparisons. Moreover, a considerable portion of construction costs go into internals (carpeting, air conditioning, heating, etc.) which are highly variable. Both the variation in construction costs with time, and in the costs of furnishings, depending on austerity, should be taken into account. But only the variation in cost due to year of construction was readily amenable to some kind of analysis. The Dodge Index provides comparative costs by year and locale that can be applied to relate construction from different years.

* Thus, negative factors registered in the Moreland study were essentially opinions because they were nullified by opposing opinions. For example, a few felt an invisible school provided no aesthetic value while some felt a distinct benefit in the preservation of open space and the natural environment.

SSI used the Dodge Index to convert all the construction costs reported in Ref. 1 to a common basis, i.e., the year 1979. These data are given in Table 1. According to the end result, if the four conventional schools had been built in 1979, the average cost/ft^2 would have been \$24.21 ± 29%, while for the fifteen* earth covered schools it would have been \$35.34 ± 41%. The percentages appended represent substantial standard deviations. This variation in the data can be shown in another fashion, as follows.

Two schools were built in two phases with both of the second phases identical to their respective first phase. Both cases involved a six year period between phases (see Blanchard and Weleetka in Table 1). It is evident that the cost of the second phases relative to the first for all figures projected to 1979 costs, is 72% for Blanchard and 126% for Weleetka, i.e., suggesting a variation in the neighborhood of ± 27%. If a variation (or uncertainty) this large is evident in the procedure for projection of costs six years later in time, there will be an even greater uncertainty in attempting to compare the 1979 price estimates for all schools (where some projections exceed six years of compounding). When all schools are included, the 1979 estimates of average costs for the two types of school indicate the earth covered schools would cost 46% more. This is likely high due to compounding errors.

It is preferable to make cost comparisons on a one-to-one basis using facilities built in the same year and to use the Dodge Index to compare where there are only one year differences. Even then, a sufficient number of comparisons (a dozen or more) are required to obtain meaningful results. Unfortunately, there are not many such opportunities in the data of Table 1; only three pairs can be used in this fashion. Hydro and McLoud were both built in 1975 and the underground, Hydro cost 60% more to build per ft^2. Highland East was built in 1977 while both Tupelo and Weleetka (Phase 2) were constructed one year later, when costs were 14.5% higher (according to the Dodge Index). There is clearly not such a big advantage for the conventional construction then. In such case Tupelo was constructed at a cost 21% lower, and Weleetka (Phase 2) at a cost 8% higher, than the conventional Highland East. The extremely limited data from these three comparisons (Hydro/McLoud, 160%; Tupelo/Highland East, 79%; Weleetka/Highland East, 108%) indicates a difference in cost/ft^2 between earth

* There ore only 13 different schools. However, the two of them that were built in two phases (six years apart) showed a different projected cost/ft^2 in 1979.

Table 1

CONSTRUCTION COST DATA

SCHOOL	YEAR BUILT	TOTAL COST	GROSS FLOOR AREA SQ. FT.	COST PER SQ. FT.	PROJECTED 1979 COST PER SQ. FT.
CONTROL SCHOOLS (CONVENTIONAL)					
Davis Jr. High	1976	$ 385,000	19,890	$19.36	$22.78
Mangum	1961	248,000	33,507	7.40	20.61
McLoud	1975	379,000	24,800	15.31	18.86
Highland East	1977	1,374,952	46,927	29.30	34.59
					Ave. = 24.21 ± 29%
BERMED SCHOOLS					
Longfellow	1973-74	841,981	36,062	23.35	34.19
Tupelo	1978	442,782	16,750	26.43	27.25
Washington	1972-73	295,000	18,067	16.33	25.88
UNDERGROUND SCHOOLS					
Bethel	1973	435,000	11,550	14.05	20.57
Blanchard*	1968	150,000	8,140	18.43	40.96
Blanchard*	1974	180,000	8,140	22.11	29.48
Davis	1967	200,000	12,500	16.00	37.47
Duke	1965	280,418	22,760	12.32	31.27
Hydro	1975	245,000	10,000	24.50	30.17
John Glenn	1967	108,240	9,840	11.00	25.76
Prague	1967	253,645	7,540	33.64	78.78
Seiling	1966	150,000	6,815	22.01	53.68
Weleetka*	1972	235,000	12,514	18.79	29.78
Weleetka*	1978	454,000	12,514	36.28	37.40
Wellston	1967	118,000	8,400	14.05	32.90
					Ave. = 35.34 ± 41%

*School was constructed in two different phases.

covered and conventional schools in Oklahoma that is less than 16%. (Many more comparisons on a one-to-one basis are required to provide a meaningful analysis, but this limited analysis suggests a 46% difference is likely to be too high. The average of the two calculations is probably more reasonable.)

The design costs for either type of school were found to be a fixed percentage of construction costs, so relative costs for the two types of construction will be the same for design as it is for construction, probably around 25% to 30% higher for earth covered than for conventional.

Real estate costs are complex and highly variable, depending on locale. The main point for FEMA to consider as a means to foster construction of earth covered schools is how much land might be saved at a particular site by constructing the school under the playground. In some locales, the real estate that would not have to be purchased could represent a significant dollar saving despite the fact this saving is probably small (or non-existent) in most of the Oklahoma earth covered schools.

Operation and Maintenance - Essentially, none of the operation and maintenance (O & M) costs listed on page 6 were maintained explicitly in the accounting records of the Department of Education. In any case, the most important of the O & M factors is the energy costs. Table 2 summarizes an analysis made by the Oklahoma Department of Education, which used the utility bills over one year to calculate usage at each school, in thousands of Btu per square foot ($MBtu/ft^2$) annually. This was subdivided into electrical and gas consumption with the electrical usage computed at 3,413 Btu per kilowatt hour (Btu/KWH). This conversion factor will give the load-demand at the end-use and eliminates the bias in cost introduced by preferential selection of electrical heating and cooling systems over other alternatives in the earth covered Oklahoma schools.

To be comparable, load demand for gas should be corrected to account for burner inefficiencies. Efficiencies of 80 to 85% are claimed for gas fired systems so that the metered values multiplied by 80% should provide more reasonable estimates of load-demand for gas.

Table 2

ENERGY CONSUMPTION DATA—ANNUAL INDEXES

SCHOOL	PERCENTAGE UNDERGROUND	ELECTRICAL MBTU/FT^2	NATURAL GAS MBTU/FT^2	TOTAL USAGE MBTU/FT^2	TOTAL COST $/FT^2
		CONTROL SCHOOLS			
Mangum	0	14.9	75.8	90.7	0.38
McLoud	0	20.6	73.6	94.2	0.34
Davis Jr. High	0	21.0	26.7	47.7	0.23
Highland East	0	40.0	47.0	87.0	0.47
		BERMED SCHOOLS		Ave. = 79.9 ± 27% 0.8 x Ave. = 63.9 ± 27%	
Longfellow	0	26.6	27.0	53.6	0.31
Washington	0	35.5	– –	35.5	0.33
		UNDERGROUND SCHOOLS			
Bethel	15%	36.9	20.5*	57.4	0.46
Blanchard	67%	39.9	—	39.9**	0.41
Davis	100%	48.2	—	48.2**	0.46
Duke	66%	29.2	—	29.2**	0.29
Hydro	19%	20.6	22.1	42.7	0.26
John Glenn	16%	29.0	38.4	67.4	0.35
Weleetka	25%	25.9	36.3	62.2	0.35
Wellston	10%	22.0	13.8	35.8	0.24

*Propane

1 MBTU = 1,000 BTU

** Ave.=39.1 ± 24% for these three schools

Another factor that must be considered regarding the data presented in Table 2 is that the annual usage in MBtu/ft^2 has been allocated based on the percentage of the facility (because it is serviced by a single meter) that is underground. As the percentage of the facility representing the earth covered portion decreases, eventually the information sought is lost in the statistical variation in the energy consumed within the conventional portion of the facilities — one of the unknowns it is desired to measure. The only practical and simple way to obtain the desired data is to meter the earth covered portion of each facility separately (which requires installing meters). In the meantime, a very rough estimate of the difference in energy consumed can be obtained by using the data from the schools that have at least 66 percent of the facility underground. (Note that there is an error in Ref. 1. Blanchard school is 66.6% underground.) This gives a total usage of 39.1 MBtu/ft^2 ± 24% for earth covered schools compared with 0.8 x 79.9 MBtu/ft^2 ± 27% or 63.9 MBtu/ft^2 ± 27% for conventional schools. Based on this limited data, the indicated energy saving in building an earth covered school is 63%, annually — even without benefit of energy conservation design.

Security Aspects

Disaster protection against tornadoes has provided the impetus for design and construction of underground schools in Oklahoma. However, underground structures can protect people against a much broader range of natural and man-made disasters. Scientific Service, Inc. made an analysis of just how much might be possible.

The ability of a structure to provide shelter against physically disruptive forces such as tornadoes, hurricanes, hailstorms, or high winds is related to the loading the structure can withstand. Building a structure underground, or covering one with earth, enables the strength of the structure to be augmented by the strength of the soil around it. Moreover, such structures are inherently stronger than those above ground because they must resist the pressure of the soil. By making the structure strong enough to support a soil cover of three feet, it will be sufficient to hold the roof on against tornadoes, high winds, etc.; will protect against thermal radiation, hailstorms and falling objects; be very effective against fallout radiation; and could be made effective against a

nuclear attack. From studies conducted by SSI on expedient methods for upgrading structures (Ref. 2) it seemed reasonable that these things could be accomplished relatively inexpensively.

Table 3 provides a quantitative summary of the disaster protection currently afforded and what could be provided in an emergency for each of the underground schools studied. Column 2 gives the total additional load that can be superimposed on each structure without exceeding the design value. This superimposed load might be concrete, soil, or people. Column 3 gives the superimposed soil load that, if added to the bare structure, would provide disaster protection sufficient to meet virtually all circumstances (tornadoes, radiation, etc.). This soil load is given in both inches and pounds per square foot and would bring the total cover to the equivalent of 3 ft of soil.

Comparison of the data in columns 2 and 3 shows that only three schools could support the recommended soil cover load safely and permanently, as built. With a system such as depicted in Fig. 1, however, the superimposed load capability becomes that listed in column 5. Under such an emergency expedient, it is seen (column 5 vs column 3) that all but two bermed schools could be safely covered with soil to the depth indicated in Column 3. With the temporary emergency strengthening and the soil cover added to obtain a PF 1000 radiation protection, the strength remaining could resist the blast loadings indicated in the last column.

A glance at the last column data for the John Glenn and Wellston schools suggests that it would be a simple matter to conduct a disaster protection analysis and make appropriate design change recommendations for any proposed underground school so that it could be built to provide PF 1000 and resist overpressures of 30 to 40 psi. The added cost for changes is expected to range somewhere between $0.50 and $1.00 per square foot (less than 3% of total cost of an underground structure, in most cases). The analysis could be done from blueprints at a cost of less than $500 per school.

A very brief description of the basis for this study is described in Appendix B.

Table 3

RADIATION AND BLAST PROTECTION CAPABILITY OF UNDERGROUND SCHOOLS STUDIED

Name of School	Superimposed Load to Equal Design Load (psf)	Additional Soil Required to Provide PF 1000(1) (in.)	(psf)	Soil Loading Allowable in an Emergency(2) (in.)	(psf)	Maximum Superimposed Load when Strengthened(3) (psf)	Blast Protection when Strengthened and Upgraded to PF 1000 (psi)
1	2	3a	3b	4a	4b	5	6
Arnett	145	28	280	19	190	1080	5.6
Bethel (4)	277	29	290	29	290	1780	10.3
Blanchard	75	19	190	15	150	2265	14.4
Blanchard (4) Addition	100	19	190	19	190	2600	16.7
Davis	167	30	300	19	190	840	3.8
Henry Wadsworth(5) Longfellow (bermed)	35	33	330	4	40	240	0
Hydro	100	29	290	11	110	680	2.7
John Glenn(6)	245	19	190	19	190	4570	30.4
Prague	200	30	300	23	230	1360	7.4
Seiling	110	30	300	19	190	1900	11.1
Washington (5) (bermed)	30	36	360	4	40	150	0
Weleetka (6)	330	29	290	29	290	2140	12.8
Wellston (6)	300	18	180	18	180	5440	36.5

(1) PF refers to Protection Factor, from nuclear radiation. A PF 1000 is likely to be adequate for almost any eventuality.

(2) Only in an extreme emergency will it be valid to exceed the Design Load (column 2) without first strengthening the structure.

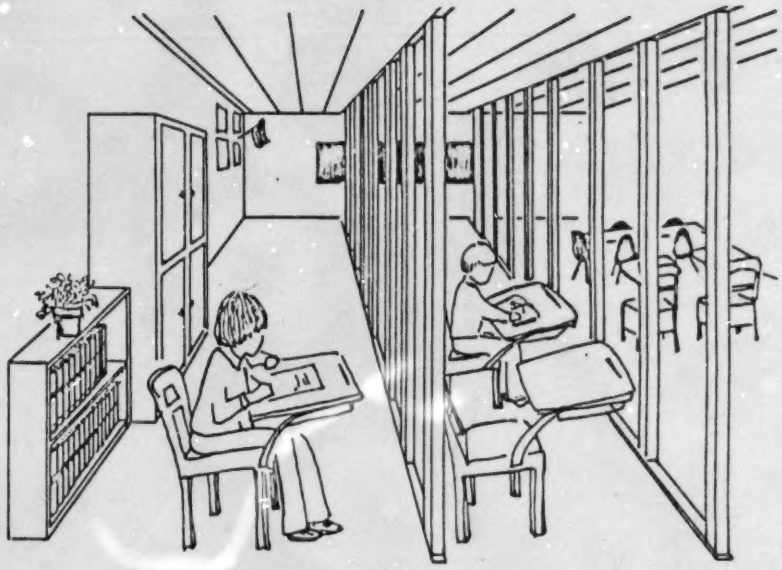
(3) An example of a temporary (expedient) option for strengthening is given in Fig. 1. Only five of the schools could be upgraded to PF 1000 without first strengthening the structure.

(4) In an extreme emergency, these two schools could be upgraded to PF 1000 without first strengthening the structure (columns 3 vs 4).

(5) These bermed structures could not be upgraded to PF 1000 even with temporary strengthening of the structure (columns 3 vs 5).

(6) These three structures could safely be upgraded immediately and permanently and not exceed the design load (columns 3 vs 2).

a. Before



b. After adding shores.

The upgrading concept applied is basically simple. In a typical structure above ground, a 2 psi loading over the surface of a wall will collapse it. In an underground structure, where the walls are protected by the soil around them, the roof is the vulnerable element and "shoring" (such as shown in the figure) will strengthen the roof and hence, the entire structure significantly. In an emergency, shores can be cut from wood posts and beams and assembled in a matter of hours. The calculations summarized in columns 5 and 6 of the table were based on this kind of emergency strengthening of the roofs in the underground schools.

Fig. 1. Example of Structural Upgrading (strengthening) Applied to an Underground School in Oklahoma.

CONCLUSIONS

Sociological, psychological, or physiological objections to earth covered schools are principally matters of opinion. Objective evidence favors earth covered schools.

The principal reasons structures are built underground at present are for protection against storms and earthquakes, energy savings, and preservation of the natural environment. In Oklahoma, all the earth covered schools were built to provide protection against storms (tornadoes); none was designed to be energy conservative. The majority involved in operating these schools felt their buildings saved energy. Limited explicit data support this belief; it appears that the saving of energy in earth covered schools could exceed 60 percent.

Existing earth covered schools offer the opportunity to strengthen the structures on short notice (several hours to 1 day) to resist high overpressures (up to 36 psi), thermal radiation, and nuclear fallout radiation.

At minor additional cost, earth covered schools could be designed to provide fallout and tornado protection for virtually any circumstance (with 3 feet of earth cover) and to be rapidly strengthened, with simple shores in a matter of hours, to withstand 40 psi overpressures.

If all public schools had this level of disaster protection, over half the population of the United States could be protected to 40 psi in an emergency.

Sufficient alternative incentives for constructing earth covered schools can probably be documented to justify considering some kind of support for a general policy to build new schools underground.

RECOMMENDATIONS

It is recommended that FEMA immediately establish a program to develop technical data that will support more frequent decisions to build new school facilities underground.

There has never been a more opportune time to attempt to develop a widespread shelter system for disaster protection on a national scale. The task should be easy to initiate right now because it can be made almost completely unobtrusive insofar as a national defense project is concerned (but while the public also has a subjective interest in national defense).

The major thrust should be a management based move to mimimize energy usage and life-cycle costs of new school facilities. For additional support, strong appeal to environmentalists should be built in by playing up the preservation of open space, as well as the benefit of dual use of the land. And an appeal to the need to provide greater protection and security for school children from natural disaster can be used as the reason for structural reinforcement.

The first step should be to initiate immediate development of technical information disaggregated according to the above mentioned factors observed to act as positive incentives in the decision process. The technical data developed should be organized so that it can be used both to attract, and then to supply, information needed by those who are part of the decision heirarchy for establishing new schools. At present, a promising opportunity exists to enlist the Department of Energy to apply the National Energy Act requirements to promote consideration of underground facilities for new school construction.

To build the technical base for any of these moves will require the development of an analytical model to predict building performance of underground schools both for energy use and structural performance. Hard data on all the nation's earth covered schools will be necessary to verify the analytical model. Backup data should be developed on structure/inhabitant

vulnerability to natural and man made disasters that encompass: tornado, hurricane, wind; falling objects, hail, rock, trees; earthquake, slides; vandalism; radiation spills, reactor failure; fires; insurance premium reductions; etc. An assessment should then be made of the national potential to benefit from constructing a major portion of new schools underground.

REFERENCES

1. " A Case for Underground Schools", prepared for Defense Civil Preparedness Agency, by School Plant Services (Bob Martin, Administrator), in cooperation with Oklahoma Civil Defense.

2. "Shelter Upgrading Manual", by Scientific Service, Inc., prepared for FEMA, (soon to be published).

3. Lutz, Frank W., Patrick E. Lynch, Susan B. Lutz, "ABO Revisited, An Evaluation of the ABO Elementary School and Fallout Shelter", final report, prepared for DCPA, June 1972.

4. Gabrielsen, B.L., G. Cuzner, R. Lindskog, "Blast Upgrading of Existing Structures", 7719-4, final report, Scientific Service, Inc., Redwood City, CA, January 1979.

5. "Blast Upgrading of Existing Structures, Phase II", Scientific Service, Inc., (soon to be published).

APPENDIX A

TRENDS IN EARTH COVERED SCHOOLS: THE OKLAHOMA EXPERIENCE

Moreland Associates Fort Worth, Texas April 1979

SYNOPSIS

A conference was held in Oklahoma City on February 22, 1979. The purpose was to explore trends and experiences in building earth-covered schools in Oklahoma. Participants included twelve school district superintendents, principals and teachers as well as representatives of two school districts which did not have earth-covered schools. The conference focused around several discussion topics including:

Reasons leading to the use of underground schools.

Underground schools as Learning Environments.

Trends in the use of underground schools.

REASONS FOR BUILDING

In most cases protection from tornadoes was the underlying reason for building earth-covered schools. Many of the schools also serve as community storm shelters. During the course of the conference, however, other reasons were also mentioned, such as energy costs reduction, fire safety and open space conservation.

Most participants felt that their underground schools were more energy-efficient than above-ground schools. Unfortunately, the amount of reduction was not often known. In many cases, the underground school was metered along with an above-ground

facility.

While the initial construction costs of building underground were slightly higher than costs of building comparable schools above ground, these higher initial costs were considered to be offset by long term savings. The long term savings come primarily from decreased costs of maintenance, operation and repair.

SCHOOLS AS LEARNING ENVIRONMENTS

It appears that teachers and students, the primary users, feel that their schools perform exceptionally well. Teachers and principals alike commented on the lack of noise and distractions in the underground schools and the ease with which they could keep the attention of their students.

Educators were asked directly if there had been any problems with students complaining of headaches, blurred vision, fatigue, nausea or behavioral changes. The only comment made along this subject was that several students requested transfer to underground schools for allergy relief.

A strong attitude that emerged from the conference discussion was the sense of security felt by community members in knowing they have a shelter from tornadoes. However, some participants reported that underground schools may not be easily identified as a community landmark.

TRENDS

Oklahoma has constructed at least nine earth-covered schools since 1965, and perhaps 15 more with earth bermed walls. It appears that users are satisfied with their schools.

The consensus of the conference participants was that they would all build underground again. To quote one superintendent, "We're sold on underground. If you're in a position to do it, there's no other choice."

INTRODUCTION

This report summarizes a conference held in Oklahoma City on February 22, 1979. The purpose of the conference was to explore trends and experiences in building earth-covered schools in Oklahoma. Conference participants included twelve school district superintendents, principals and teachers, who related their experiences with earth-covered schools. Also included were representatives of two school districts which did not have earth-covered schools, and representatives of state agencies. The conference focused around several discussion topics, which were:

A. Reasons leading to the use of underground schools.

B. Underground schools as learning environments.

C. Trends in the use of underground schools.

This report discusses each of these topics in the same order.

Most of the comments mentioned in this report are on tapes, but it is often difficult to match a name with a voice on a tape. The other comments are on questionnaires.

A: REASONS LEADING TO THE USE OF UNDERGROUND SCHOOLS

The primary reason for building underground schools was storm protection. During the course of the conference,

however, auxiliary reasons mentioned were energy savings, reductions in facility costs, fire protection and conservation of open space.

1. STORM PROTECTION - It was stated that an average of 54 tornadoes per year are sighted on the ground in Oklahoma. Thus, storm protection was the underlying reason for building earth-covered schools. In many cases, underground schools were built with the understanding that the school would provide sanctuary for the community in the event of tornadoes. Several participants commented that citizens of the community come to the schools for protection during storms, and that the schools are apparently highly prized for their use as protective structures.

2. ENERGY CONSIDERATIONS - Most participants were confident that their underground schools were more energy-efficient than other schools. Unfortunately, the amount of reduction was not often known. In many cases, the underground school was metered along with an above ground facility. One participant stated that he did not feel that there were energy savings with his school; however he further stated that their cooling unit, installed in 1966, did not operate efficiently and that installation of a newer unit would show marked reductions in energy costs. The superintendent

from Duke related that he paid an unscheduled visit to his school during the Christmas vacation. Even though the school had not been operaed for one week, the inside temperature was 68° to 69° while it was 0° outside.

3. REDUCTIONS IN FACILITY COSTS - While the initial construction costs of building underground were slightly higher than costs of building comparable schools above-ground, these higher initial construction costs were offset by long-term savings. The long-term savings come primarily from decreased costs of maintenance, operations, and repair. For example, the superintendent from Duke schools, pioneers in building underground schools in Oklahoma, reported that their school was built in 1964 for $1 more per square foot than a similar above-ground school. Over the years the Duke system has experienced reduced costs of both interior and exterior maintenance. A further benefit was the significantly lower insurance rates on their underground building. Furthermore, losses due to vandalism have been practically non-existent.

4. FIRE PROTECTION - In one school district a fire that devastated an above-ground school caused officials to drop their plans for a new above-ground school; instead, they built underground.

5. OPEN SPACE CONSERVATION - Another advantage that has emerged deals directly with conservation of open space. An urban district that was faced with a choice between playground space and construction of a school found that they could have both by building underground. Several rural schools also reported uses for the earth cover. Earth-covered schools, like other earth-covered buildings, make possible dual use of the land available, conserving open areas.

B: UNDERGROUND SCHOOLS AS LEARNING ENVIRONMENTS

Conference participants focused on their observations of student behavior and on community attitudes toward the underground schools. It appears that teachers and students, the primary users, feel that their schools perform exceptionally well.

The comments of the participants are summarized in the following notes:

1. LEARNING ENVIRONMENT - Teachers and principals alike commented on the lack of noise and distractions in the underground schools. Teachers especially commented on the ease with which they could keep the attention of their students. The superintendent from Prague noted that their mentally retarded - mentally handicapped students were moved to the underground

building because the lack of distraction provided a superior learning environment. Rather than the distraction provided by windows, teachers can use all four walls to stimulate learning.

As an aside, we note that a principal in Texas, Mr. Kittrell, with the underground junior high school in Lake Worth Village for twelve years, confirms that he feels his school provides a superior learning environment. Dr. Frank Lutz with the Pennsylvania State University is probably the ranking authority on the subject. In reference to the underground school in Abo, New Mexico, a school he has studied extensively twice, Dr. Lutz states: "Apparently other schools could be so constructed and if operated under similar conditions, would also serve as effective elementary schools." He further states, "In my view sufficient research has been done to establish that people within the normal range of the population will suffer no adverse psychological effects from living or working in earth-covered structures."

Conference participants were asked to relate any instances of phobia, apprehension, or psychological disturbance on the part of students that could be in any way related to being underground. There were none.

One teacher commented that "I never really knew I was underground and neither did the children." A frequent comment was that students wondered about the weather and if they needed coats for the playground, but the only reported expressions of concern were during tornadoes. Then children were apprehensive that they would find their homes demolished when they left the safety of the school. Tornadoe safety has not been established for all types of earth covered structures, but it is generally felt that a concrete structure with 18" or more of earth and proper ventilation would likely survive a tornadoe.

It appears that teachers and pupils alike relate well to their underground schools. In one school district, only one teacher in eight years asked to be transferred from an underground school. However, it was not known whether being underground caused the transfer request. In another school, space considerations necessitated moving two grades to an above-ground school. Some time later the teachers reportedly said that they wished they were back underground.

2. PHYSIOLOGICAL EFFECTS - The conference addressed the issue of physiological effects in terms of specific complaints such as headaches, blurred vision, fatigue, nausea and behavioral changes. One educator mentioned

that at one time students in one underground school had become lethargic in the afternoons; however, after proper ventilation levels were established, the problem was solved. In another instance, two girls fainted during a storm emergency when their school was crowded with three times the usual number of people.

Asthma and allergy relief because of the lack of dust were positive physiological effects noted as a generally unexpected result of building underground. In the Duke earth-covered school to which persons with allergies were transferred, the superintendent reported that a student in the school had said that she loved coming to school because it was the only place where she could breathe. Allergic students had been assigned to the earth-covered school, and for this group of students, learning should be significantly enhanced by the relief of chronic allergic symptoms.

3. COMMUNITY ATTITUDES - A central attitude that emerged from conference discussion was the sense of security felt by community members in knowing that they have a shelter from tornadoes. It appears that several of its communities are pleased that they have a storm shelter. Most of the principals reported being awakened at night during storms by community residents seeking shelter. Some of the earth-covered schools are in small

communities consisting chiefly of outlying farms. Since a major reason for building underground was storm protection, it continues to dominate the community attitude. Participants reported that for some residents underground schools may not be easily identified as a community landmark. One community reported regret in not being able to "see it being built" as much as usual.

It seems that several communities have been pleased by visits from officials outside the school districts who are seeking advice and expertise in building underground schools in their own districts.

C: TRENDS IN THE USE OF UNDERGROUND SCHOOLS

There are several things to consider in developing a basis for expectations about the future of underground schools in Oklahoma. First, are the users satisfied with their schools? Second, what changes in the design of such schools might result in an expansion of their use? Third, what major factors are facing decision makers:

Oklahoma has constructed at least nine earth-covered schools since 1965, and perhaps 15 more with earth bermed walls. It appears that the users are satisfied with their schools.

Even though the educators were significantly in favor of underground schools, they mentioned some changes they would like to see in underground school construction. For

instance, consideration should be given to the type of air treatment units to be used. The air treatment system should be designed specifically to ensure that it is compatible with underground construction. Another frequent comment related to energy metering. To establish the energy usage of earth-covered schools, separate metering of each building or special function area was recommended. Currently, most earth-covered schools are metered with above grade buildings. There is a lack of hard evidence regarding reduced energy use due to mixed metering.

Several school principals suggested that proper techniques of waterproofing resulted in their dry buildings. Several other principals suggested that those techniques would be used the next time they built.

There was discussion at the conference about alternative construction methods, amounts of earth cover, uses for roof space, and alternatives to access ramps. The discussions were conversational and informational in nature. After those discussions, there was a brief slide show of several recent earth-covered buildings. The participants were asked to respond to four questions aimed at gauging their opinions about the future acceptability of underground schools. Between 85% and 100% of its participants (fourteen people) agreed with each of the following statements:

Earth-covered schools can provide good learning environments.

I might prefer an earth-covered school, depending on the design.

Earth covered buildings can provide an acceptable quality of surrounding.

The energy, safety, and maintenance performance of some earth-covered schools merits consideration.

Based on these opinions and the general tone of the conference, there seems to be a firm basis to expect that informed school systems would consider earth-covered schools as viable alternatives and worthy of serious consideration.

There is also evidence that communities which build one earth-covered school tend to build more. For instance, Santa Anna, California (three underground schools since 1974) and Fort Worth, Texas (two underground schools since 1978, and a new underground central library in 1977) have decided repeatedly for earth-covered alternatives. Also, Fairfax County, Virginia, the largest school district in the county, is constructing its second solar energy and earth-covered school. If the level of user satisfaction with those communities is as high as it appears, then other communities might more readily decide to try an earth-covered alternative.

There appear to be three major factors influencing decision-makers that deserve comment. First, there is growing evidence that taxpayers want a long-term reduction in taxation

or its growth. Also, there is evidence that revenue requirements for energy, maintenance, operations, and insurance for earth-covered buildings are likely to be dramatically less than the requirements for comparable above grade buildings. Thus, an increased use of earth-covered schools may be consistent with voter sentiments.

Second, there is a factor existing in much of Oklahoma which may limit the incidence of earth-covered schools. The factor is a state law limiting the level of taxation for new school construction. One purpose of the law may be to retard the rate of inflation and tax growth by fiat. One result of such laws is often to favor less expensive building technologies. For instance, earth-covered buildings often cost more to build than conventional buildings. However, some decision-makers judge that the long-term economy of earth-covered buildings justify a greater construction cost. Several superintendents at the conference commented that maintenance and operations revenues were more readily available than bond election revenues. This situation is thought to act in an inhibiting manner with respect to decisions for earth-covered schools.

The third factor has to do with a shrinking national demand for new school buildings due to the reduction in the population rate. With fewer schools to build there may be more funds available per school without increases in taxation, thus

higher performance schools may be more seriously considered. However, many school districts will continue to need facilities expansion programs.

APPENDIX I

RESULTS OF BACKGROUND INFORMATION SURVEY:
OKLAHOMA UNDERGROUND SCHOOL STUDY

Occupation-
Superintendent, 10; Deputy or assistant superintendent, 2; Principal, 2; Teacher, 1.

Is your place of work in an underground school?
Yes, 4 No, 5 Partially, 3

Do you think that underground schools provide a healthy environment for learning? Why?
Yes, 14 No, 0

Comments - Ideal setting for learning, fewer distractions, multi-purpose.

What were the reasons for building your underground achool?

Storm shelter	12
Low operating costs(including energy)	5
Lack of above-ground space	5
Low maintenance costs	3
Better learning environment	1
Combat vandalism	1

Does your underground school do a (good) (fair) (poor) job of meeting student's needs?

Good	13
Fair	0
Poor	0

What do you like about your underground school?

Low operating cost	6
Quiet	4
Storm protection	4
Energy efficient	3
Vandalism savings	3
No distraction	3
Space saving	1
Only partially underground	1
Lower insurance rates	1

What do you dislike about it?

Nothing	5
Air-conditioning problems	3
Leakage	3
Lack of restrooms and drinking fountain	1
Inconvenient access	1
No exposure to community to show school	1
Energy cost	1
Expansion limitations	1

RESULTS OF SURVEY (continued)

How could your school be improved? What improvements would you suggest for future schools?

Air conditioning with less upkeep	4
Dirt fill on top	2
Build into hillside	2
More space	2
Better way to get supplies into building	1
Finish insulating	1
Restrooms	1
Storage	1
Extra exit	1
More sturdy building	1

Briefly describe your school.

Duke - constructed 1965
No windows, 16 to 18 " of dirt on top, 15 classrooms, offices and cafetorium, 4 restrooms, storage area, 170' by 135'

Moore
Control school

Wellston - constructed 1972
No windows, 2' of earth on top, 8 classrooms, library, ramps at each end, restrooms, drainage gravel under floor, concrete beams and ceiling.

John Glenn Elementary Oklahoma City - constructed 1967
aboveground - 33 classrooms, 2 cafeterias, gym, library, offices
underground - 10 classrooms, office storage.

Seiling - constructed 1966
6 classrooms, tennis court on roof, no windows

McLoud
Control school

Western Heights, Oklahoma City (no date given)
300 students, no windows, 12 classrooms, another building on top

Prague - constructed 1967
18" earth on top, no windows, 7 classrooms, 170 students

Shawnee Bethel Jr. High - constructed 1973
Another building on top, 300 students, 3' earth on top, "sold on underground"

Davis - constructed 1967
10 classrooms, office area, teacher workroom, restrooms, library, 8" dirt on top, 340 students, each room opens to central courtyard

APPENDIX II

OPINION INFORMATION: UNDERGROUND SCHOOL STUDY

QUESTIONS	RESPONSES		
	strongly agree	no opinion	strongly disagree
1. Earth covered schools can provide good learning environments.	14	0	0
2. I might prefer an earth covered school, depending on design.	12	2	0
3. Earth covered buildings can provide an acceptable quality of surroundings.	13	1	0
4. The energy, safety and maintenance performance of some earth covered schools merits consideration.	13	0	0

RESULTS OF SURVEY (continued, 2)

Weleetka - constructed 1972, addition 1978
2 schools, 7 classrooms in one and 9 classrooms in another. restrooms, offices, storage, 4' of earth on top

Hydro - constructed 1975
10,000 square feet, concrete poured walls and top, no windows, 8 classrooms, office, teacher work area, restrooms, storage area, lift pump for sewage.

Washington (no date given)
Berm construction, 9 classrooms, library, offices

APPENDIX II

OPINION INFORMATION: UNDERGROUND SCHOOL STUDY

1. Earth-covered schools can provide good learning environments.

Strongly agree		Strongly disagree
1	5	9

2. I might prefer an earth-covered school, depending on design.

1	5	9

3. Earth-covered buildings can provide an acceptable quality of surrounding.

1	5	9

4. The energy, safety and maintenance performance of some earth-covered schools merits consideration.

1	5	9

BACKGROUND INFORMATION: OKLAHOMA UNDERGROUND SCHOOL STUDY

1. Your name
2. Occupation
3. City or town
4. Name of school
5. Is your place of work in an underground school?
6. Do you think that underground schools provide a healthy environment for learning? Why?
7. What were the reasons for building your underground school?
8. Does your underground school do a (good) (fair) (poor) job of meeting students' needs?
9. What do you like about your underground school?
10. What do you dislike about it?
11. How could your school be improved? What improvements would you suggest for future schools?
12. Briefly describe your school (how much earth on top, does it have windows, how many students or classrooms, etc.)

APPENDIX B

BASIS FOR PREDICTION METHODOLOGY FOR EARTH COVERED SCHOOL STRUCTURES PERFORMANCES

The radiation and blast protection capabilities of the underground schools studied (Table 3) are based on failure prediction methodologies developed by Scientific Service, Inc. in an extensive 6 year research program conducted for the Defense Civil Preparedness Agency (now the Federal Emergency Management Agency). As a result of this extensive research program, Scientific Service was able to develop practical techniques for predicting structural failure and to verify these failure predictions with actual structural test data that were developed both by Scientific Service, Inc. and others.

The analysis and prediction techniques are applicable to wood, steel, and concrete roof and floor systems, loaded statically, dynamically, and in combination. The prediction methodology is founded on engineering mechanics, limit theory, and a statistical approach to failure analysis that enables realistic assessment to be made of failure probabilities based on the combined effects of statistical variation in materials, structural elements, and construction processes.

To date, Scientific Service has conducted load tests to failure on 13 wood floors, 3 reinforced concrete floors, and 4 open-web steel joist floors with metal deck and concrete topping (Refs. 4 & 5). Each type of construction tested included a minimum of one base case test; i.e., "as built" without any upgrading. The additional tests in each type-group incorporated various upgrading schemes appropriate to that construction type. For example, the concrete floors were tested with shores at midspan and at the one-third points, the open-web steel joist floors were tested using a stress control approach, with shores which enabled the stresses to be controlled in the various portions of the structure such that each portion of

the structure could achieve its maximum capability. The wood floors were shored at various locations commensurate with other upgrading schemes such as flange, boxed beam, and king post truss. Each of these tests was evaluated with respect to its predicted failure and the actual results. Analysis to date indicates significant correlation in these areas, and additional testing is planned.

A comparison of the test results from the Scientific Service tests with the predicted failures on Table 3 (see last column) indicates that the predicted values for concrete slabs are on the conservative side. The test sample was a one-way reinforced concrete slab, 6½ in. thick, and failed at a load of 34.0 psi (Ref. 5) when shored at the one-third points. These results would compare very favorably with the 8-in. thick slabs of the Blanchard and the Blanchard addition, which were predicted to fail at 14.4 and 16.7 psi, respectively, the 10½-in. thick slab of the John Glenn, predicted to fail at 30.4 psi; and the 11-in. thick slab of the Wellston, predicted to fail at 36.5 psi. The predictions for these four schools were based on assumed one-third point shoring.

The comparative results from the open-web steel joist tests of 7.5 psi for one-third point shoring (Ref. 5) also are favorable with respect to the Davis school prediction of 3.8 psi for one-third point shoring.

Scientific Service has just completed the final draft of a Shelter Manual (Ref. 2) which incorporates this prediction methodology. This manual is intended for use in the identification and the upgrading of shelter spaces to support Crisis Relocation Planning, and illustrates a number of typical potential shelter areas and the various methods which may be used to upgrade them. The majority of the upgrading methods suggested in this manual were tested during the above program (Refs. 5 and 2).

In summation, the methodology being developed promises to provide a potent analytical tool for quantitative assessment of failure loads in existing structures, before and after upgrading. Moreover, when the

procedure is applied, it will provide the data necessary for incorporating the most economic modifications into the structure at the design stage to increase its blast protection capability for last minute upgrading.

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An Empirical Study of Earth Covered Schools in Oklahoma

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DCPA 01-78-C-0265 Work Unit 1151E

-Abstract-

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